

## 2. Urban geology of Swansea and Port Talbot

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The conurbation of Swansea–Neath–Port Talbot is one of the main centres of industrial development in South Wales. A long history of mineral extraction and processing, which stoked the initial growth of the towns, declined during the 20<sup>th</sup> Century. Many of these former industries have left a legacy of groundwater, water-course and land contamination.

A project funded by the Environment & Hazards Directorate (British Geological Survey) between 2000-2005 used available geological data to determine potential areas of contaminated land and understand the influence of the geology to pollutant pathways (Waters *et al.*, In press a). The study covered 100 km<sup>2</sup> of the Swansea–Neath–Port Talbot area (Fig. 2.1) and was aimed at providing data relevant to contaminated land issues, to augment the study by Arup (1997) on earth science information relevant to planning and development for the Swansea-Llanelli district, and look at new methodologies of presenting the data.

Contaminated land is defined as areas where a *Source-Pathway-Receptor* linkage can be established (DoE, 1995). In order to determine *Source* areas it is necessary to appreciate the industrial development of the region by collecting information on current and former land use and the extent and nature of artificial deposits. The degree that contamination of *Source* areas is a problem can be established from analysis of soil geochemistry. The *Pathway* component represents the migration of contaminants through the air, surface water or groundwater. It is the groundwater pathway, in particular the influence of superficial deposits and bedrock, which is most poorly understood. The study of the hydrogeology of the region provides an insight into the

inherent complexity of the migration of potential contaminants in the groundwater.

The above topics are described in turn for the study area.

## **Industrial development**

### **History of urban growth**

Urban growth commenced with the Norman occupation and establishment of Swansea Castle and Neath Abbey. Extraction of coal from the area commenced in earnest in the 18<sup>th</sup> Century and led to major population expansion in Swansea and Neath and development of a further port at Port Talbot (Fig. 2.1).

The docks developed as the main arteries for the import of ores and export of coal. Coal was used to fuel the developing smelting industry in the Lower Swansea and Neath valleys. In the 18<sup>th</sup> and 19<sup>th</sup> centuries copper, lead, silver, arsenic and zinc were smelted in 22 plants along the Lower Swansea Valley (Bridges, 1999). Copper smelting had early predominance with many of the works located adjacent to the River Tawe in the lower part of the valley. The copper industry declined after 1880 and was replaced by zinc (spelter), with the works concentrated on the east side of the Lower Swansea Valley. Ten steel and tinsplate works were established late in the 19<sup>th</sup> Century, largely adjacent to the River Tawe. After 1928, these became the major industry in the Swansea area. Other ore processing plants smelted silver and lead, arsenic in association with copper, nickel in association with copper, and cobalt, used for colouring glass and paints.

The interfluvial areas commonly have steep slopes, which have restricted urban development. The main area of housing in Swansea was historically located to the west of the River Tawe, principally to be upwind of the airborne pollution from the smelting industry. Other housing developments were restricted to the lower slopes of

the Neath valley. These urban areas, including associated recreational areas, school fields and allotments, are the main *Receptors* within the study area.

Large-scale abandonment and dereliction of the smelters occurred after the end of the Second World War. The closure of these industries left a legacy of polluted wastelands and during the latter part of the 20<sup>th</sup> Century there has been a major scheme to redevelop the Lower Swansea Valley into a business and manufacturing Enterprise Park. Further redevelopment schemes have led to the regeneration of the former chemical works in Baglan Bay and the oil refinery at Llandarcy.

### **Potentially contaminative land use categories**

The distribution of potentially contaminated land use has been delineated from a series of modern and historical OS maps ranging from 1877 to 1998. The main categories, discussed in Table 2.1, have been chosen as they represent common forms of land-use in the project area, which may result in contamination.

The presentation of these land uses on a map carries significant caveats, some of which were identified by Power & Statham (2004).

- The history of smelting and processing metals in the Lower Swansea Valley commenced about a century before the 6 inch to 1 mile-scale Primary Glamorgan County Series topographical maps of 1877, and hence a significant phase in the early industrial development of the region is not considered with respect to former land use.
- Initiation, growth and closure of an industrial site can occur between phases of historical map, and hence not be included in the study.
- There can be difficulty in defining the precise limits of sites from historical maps.

- The activity associated with a site may extend beyond the site boundary, for example through tipping.
- The historical maps do not provide a comprehensive source of information, but provide a guide to the broad land use pattern at a series of time intervals.

Despite these difficulties, the identification of potentially contaminated land through the study of historical and current land use is a primary procedure identified by Part IIA of the Environmental Protection Act 1990 and has been utilised in this study.

## **Artificial deposits**

Areas and types of artificial deposits have been determined from historical OS map records, aerial photography, borehole data and field investigation. The heterogeneity of artificial deposits makes the classification of such deposits on the basis of composition particularly difficult. However, it is important to have an indication of the broad make-up of artificial deposits so that potential presence of toxic residues can be predicted, and can ensure that site investigations are designed to assess their presence. The hierarchical approach used in this study represents a combination of morphology and land use.

Three classes of artificial ground are recognised in this project, Made Ground, Worked Ground and Infilled Ground, defined as displaying distinct morphological characteristics. These artificial deposits may dramatically and often unpredictably vary in thickness across a site.

### **Made Ground**

Made Ground is deposited upon natural rock or superficial deposits. It is common throughout the study area, but most extensive in the Swansea, Neath and Port Talbot

urban centres (Fig. 2.2). In these urban areas, the topographic features associated with specific areas of Made Ground, especially colliery and metal works spoil, have been smoothed over during subsequent development. Commonly, within the urban areas there have been several generations of land use and associated deposition of Made Ground at a single site.

Spoil from metal works represents the main potentially contaminative source of Made Ground in the study area. For a long time, slag had been used as hardcore throughout the area. From 1967, with the commencement of the Lower Swansea Valley redevelopment scheme, spoil was used to raise the level of the Tawe floodplain and in the construction of engineered embankments. Bridges (1999) detailed the history of the main movements of tip material within the valley. Uncontaminated till deposits were spread over the areas of land raising fill to act as a impermeable seal to the contaminants and as a growing medium for plants and trees.

### **Worked Ground**

Worked Ground consists of areas of excavation by man. The main areas of Worked Ground comprise engineered and mineral excavations. Quarrying operations in the study area (Fig 2.2) have largely been for sandstone, clay and coal. The waste material from these operations, in particular sandstone quarrying, were often tipped adjacent to the quarries to form spoil mounds of Made Ground. Unfilled quarries should represent a lower risk of contamination than filled sites. However, unfilled quarries may contain small quantities of toxic or polluting residues. Quarries and pits also have an influence on surface and groundwater flow.

## **Infilled Ground**

Infilled Ground comprises areas of excavation by man, subsequently infilled by artificial deposits. Occasionally, quarries would be partly filled with spoil after the cessation of mineral extraction. However, in most cases quarrying operations produced voids suitable for infilling with imported waste. The common types of fill include excavation waste, construction and demolition waste, domestic refuse and industrial waste. Where quarries and pits have been restored and either landscaped or built on, there is often no surface indication of the extent of the backfilled void. The large disused Cwmrhydyceirw Quarry was being infilled as a controlled operation using impermeable liners during the duration of the study.

Within the study area there are comparatively few examples of engineered excavations that have been subsequently infilled. The Swansea Canal was locally infilled by waste from the Morfa Copper works.

## **Natural superficial deposits**

The nature of the superficial deposits in the South Wales Coalfield is summarised by Wright (1991), particularly in the context of their engineering significance. The lithology, distribution, thickness and relative permeabilities are summarised in Table 2.2. The importance of these deposits to the study is their influence on groundwater flow paths and rates.

Natural superficial deposits extend over much of the lower ground of the study area, including the coastal area and river valleys, and form a thin mantle over some of the upland areas. The distribution of the natural superficial deposits at surface or beneath artificial deposits is shown in Fig. 2.3. They were deposited either in response

to glaciations during the Pleistocene epoch (1.8 Ma to 0.01 Ma) or subsequent post-glacial deposition during the Holocene (10,000 BP to Present).

## **Glacial deposits**

The most dramatic feature of the glacial geology is the presence of over-deepened palaeovalleys currently occupied by the rivers Tawe and Neath. These rock basins were first recognised by Codrington (1898) from boreholes drilled during the construction of the South Wales Railway. The results of further borings were reported by Anderson (1968; 1974), and geophysical surveys by Al-Saadi & Brooks (1973). The rock basins were excavated during the final Late Devensian glaciation, when valley glaciers spilled southward through the coalfield region to coalesce into a piedmont lobe in Swansea Bay (Culver & Bull, 1979).

The geometry of the palaeovalleys is evident in the rockhead model produced by this project (Fig. 2.4), derived from 752 boreholes used in conjunction with known surface geology to generate rockhead contours. The rockhead surface of the Swansea palaeovalley defines distinctive NE-SW trending basins, deeply scoured (up to 60 m below OD) confined by a lip at the entrance to Swansea Bay. The Neath palaeovalley lacks the deeply incised glacial scour geometry evident within the Swansea Valley and is not confined at its seaward margin. The Neath palaeovalley comprises a system of multiple buried channels, suggesting that during deglaciation it was predominantly an active outwash channel. There is evidence of channel switching and outflow at the mouth of Neath valley, with fluvial incision leaving isolated hills of bedrock at Briton Ferry and Jersey Marine.

Till is the main deposit of the Late Devensian glaciation in the project area (Fig. 2.3). It occurs as a generally thin blanket in the interfluvial areas and forming the basal fill of the palaeovalleys (Fig. 2.5). The deposits include lodgement tills that formed

underneath the moving glacier, melt-out tills formed of material released from the ice during glacier retreat, and heterogeneous ice-contact deposits or moraines. The deposits originated from the Brecon Beacons ice centre and are characterised by a clast content typically including Old Red Sandstone and Carboniferous Limestone (e.g. Bowen, 1970).

The area around the retreating glaciers was subject to periglacial conditions, where seasonal freezing and thawing were widespread. This has locally led to modification of the Till due to solifluction, the downslope movement of material by frost creep or saturated flow. The modified deposits include clast-supported gravels, including angular, frost shattered clasts, with a variable proportion of loose silty matrix, imbricated or bedded approximately parallel to the local hill-slope.

The highest parts of the interfluvies are generally devoid of Till and may have remained ice-free during the last glaciation. However, the presence of abundant erratics in these areas and glacial striae suggests that they were covered during an earlier glacial episode (Strahan, 1907; Squirrell & Downing, 1969).

The basal till deposits of the Swansea valley are overlain by up to 25 m of Glaciolacustrine deposits (Fig. 2.5), mainly comprising laminated clay and silt (Table 2.2). The deposits formed in a pro-glacial lake that probably developed during northward retreat of the valley-glacier, which was confined by the seaward lip of the rock basin (Fig. 2.4), or an ice dam in Swansea Bay. Glaciolacustrine deposits are only proved in the southern part of the Neath palaeovalley.

The youngest glacial fill of the palaeovalleys is Glaciofluvial deposits, which comprises both Glaciofluvial sheet and ice-contact deposits. The Neath palaeovalley is typically occupied by Glaciofluvial sand and gravel, which extend into the coastal zone. The sand and gravel variably incises into the underlying deposits and locally



rests directly upon bedrock (Fig. 2.5 section 3). Mounds of sand and gravel located in the Swansea palaeovalley at Landore and Glais overlie Glaciolacustrine deposits. This suggests that the sand and gravel was deposited following a re-advance phase over earlier Glaciolacustrine deposits. Terrace-like features within the valleys are more likely to comprise outwash deposits from meltwater channels issuing from retreating glaciers that dissected the moraines deposited earlier during retreat. Sand and gravel exposed on the interfluvies, particularly above Morriston typically forms mounds and ridges that are elongate in the direction of ice transport (Strahan, 1907), consistent with morainic and kame-like ice-contact deposits.

### **Post-glacial deposits**

Global sea-level rose during the Holocene, due largely to the amount of water released during de-glaciation, leading to submerging of former coastlines and deposition of new coastal-zone Beach and Tidal Flat deposits. The foreshore area preserves widespread Beach and Blown Sand deposits, which includes beach, storm beach and coastal aeolian dune deposits (Table 2.2). Beach and Blown Sand deposits form a thin veneer throughout much of the coastline. These deposits are largely obscured by developments at the Swansea docks and Baglan site.

During the Holocene, post-glacial deposits accumulated in new, superimposed drainage systems. Alluvium, including undifferentiated alluvial fan deposits, was deposited in the valleys of the rivers Tawe (2 – 5 m thick) and Neath and their associated tributaries, forming sheet-like bodies which overlie and locally incise earlier glacial deposits (Fig. 2.5 sections 1 and 2). The lower part of the Neath Valley is tidal, with Tidal Flat Deposits present (Fig. 2.5 section 3).

Following deglaciation, valley sides over steepened by glacial erosion were widely subject to landslide in the region. This probably accompanied periglacial conditions of

seasonal freeze thaw and Holocene rise in sea level, which are likely to have given rise to changes in pore pressure. Despite the presence of steep slopes, few landslides have been recognised within the study area, the greatest concentration occurring to the east on the slopes above Port Talbot and Margam. All are shallow translational slide/debris flows (Conway *et al.*, 1980) and are in argillaceous horizons and/or superficial deposits, with failure caused by seepages at the bases of Pennant sandstone scarps, or along fault planes.

As vegetation became re-established under more temperate climatic conditions, Peat deposits accumulated in upland and lowland areas of restricted drainage, typically above impermeable Till deposits or bedrock, such as the basin-like hollow now occupied by Crymlyn Bog (Fig. 2.4). Thin Peat beds are common at, or near, sea level (2 to –2 m OD) in the Swansea and Neath valleys and the coastal zone, broadly increasing in depth towards the south. A level of Peat is found in the offshore area at a depth –16 to –20 m OD, attesting to post Devensian sea-level rise. Small, isolated areas of Peat are found on the valley sides and plateaux (Fig. 2.3; Fig. 2.5 section 1).

## **Bedrock geology**

The nature and disposition of bedrock is important to the study as it influences groundwater flow paths and rates. In particular, the lithology, occurrence of joints, fractures and fissures and presence of underground coal mines strongly control aquifer properties.

The study area is located on the southern crop of the South Wales Coalfield, with bedrock geology of Westphalian (late Carboniferous) age. The succession is broadly younger toward the north of the study area, although it is significantly modified by large faults (Fig 2.6). The succession is divided into two lithostratigraphical groups,

the South Wales Coal Measures Group (hereafter referred to as the Coal Measures) and the Warwickshire Group (Waters *et al.*, in press b).

### **South Wales Coal Measures Group**

The Coal Measures are unexposed in the study area, coming to crop beneath the superficial deposits of the coastal area and underlying Swansea Bay (Fig. 2.6). The group, about 600 m thick in the study area, comprises dominantly argillaceous, coal-bearing strata, which are subdivided by marker marine bands into Lower, Middle and Upper Coal Measures (Fig. 2.7).

The Coal Measures consist predominantly of grey claystones and siltstones, commonly arranged in coarsening-upwards, coal-capped cycles that generally range from 6 to 30 m in thickness. All the coals are typically less than 1 m thick, except the Six Feet, which is 2 m thick. The coals are typically underlain by seatearths, comprising rootlet-bearing claystones and siltstones with sideritic nodules, and to a lesser extent quartzitic palaeosols ('ganisters'). Sideritic siltstones ('ironstones') are common. Sandstones are relatively few, fine-grained and are classified as quartz arenites. They are mainly thin, sheet-like bodies, which form part of the coarsening-upwards cycles. However, coarser, lenticular sandstone bodies are characterised by sharp bases resting on scoured, erosion surfaces, and conglomeratic lenses with ironstone, mudstone and coal clasts in their lower parts.

### **Warwickshire Group**

The Warwickshire Group outcrops extensively, occupying about 90% of the study area. The group, over 1500 m thick in the Swansea area, is subdivided in South Wales into a lower sandstone-dominated Pennant Sandstone Formation and an argillaceous Grovesend Formation (Fig 2.6). The Pennant Sandstone Formation is in turn

subdivided into constituent members (Llynfi, Rhondda, Brithdir, Hughes and Swansea) by laterally persistent coal seams (Fig 2.7).

The Warwickshire Group comprises predominantly (about 90%) grey-green, immature, lithic arenites, historically referred to as sandstones of “Pennant-type”. They are mostly arranged in thick, sheet-like units of very large-scale, cross-bedded and horizontally bedded sandbodies, in sets ranging up to 4 m thick, but generally about 150 to 500 mm. They are medium- to coarse-grained, typically arranged in fining-upwards cycles, with many of the sandstones underlain by conglomerates. The remainder of the group consists of claystones and siltstones with minor fine-grained sandstones that form laterally persistent beds, which contain coal seams (mainly at their tops) up to 1.8 m thick, most of which are thick enough to have been worked.

## **Structure**

The study area lies on the southern limb of the South Wales Coalfield, which is a broadly asymmetric, east-west – trending syncline. The rock strata dip steeply (c. 32 to 50°) northwards in the coastal part of the study area, but the dip decreases northwards towards the axis of the syncline, which lies about 1 km from the northern limit of the study area on the east side of the Swansea Valley Fault. Local variations are imposed on the regional dip of the strata in the vicinity of the numerous faults.

Faulting is ubiquitous in the study area and comprises four main elements (Fig. 2.6):

- The Swansea Valley Fault, a major NNE-trending fault zone that outcrops in the Tawe Valley and throws down to the east.
- The Neath Disturbance, a major north-east – trending fault zone along which the Neath Valley is carved and which throws down to the north-west.

- The Moel Gilau Fault, a roughly east-west extensional fault that outcrops in the coastal zone in the south-east. It throws down to the south.
- A suite of major, broadly north-south - trending faults spaced at 1 to 2 km intervals, which are truncated or displaced by the Neath Disturbance; to its south-east, the faults have a north-north-west trend. To its north-west, they are generally north-south, but with north-west – trending splays locally.

Both the Swansea Valley Fault and Neath Disturbance have a long history of movement, evident as broad zones of strongly folded strata with numerous small faults.

## **Soil geochemistry**

### **History of research**

Early studies into the soil contamination in the Lower Swansea Valley (reproduced by Bridges, 1999) identified strongly acid soils (pH 4.5) and very high metal amounts, e.g at Nant-y-Fendrod (Davies, 1965).

Subsequent localised studies have determined the influence of vegetation and soil acidity on the solubility and mobility of metals in the soil. A process of tree planting was determined to be responsible for lead accumulation at the soil surface and removal from deeper within the soil profile, whereas copper, zinc, nickel and cadmium appeared to have been leached and precipitated at deeper soil horizons where pH was slightly higher (Chase, 1978; Bridges *et al.*, 1979). In a study of an undisturbed copper tip, it was shown that leaching by rainwater had established a pH gradient, more alkaline at depth, with enrichment of copper at 0.4 m depth and zinc at 0.8 m depth (Chase & Wainwright, 1983).

A NERC Urgent Project in the Lower Swansea Valley funded from 1999 – 2003 has provided analyses of soil, vegetation, water and stream sediment from samples collected on a monthly basis, in order to investigate spatial patterns of pollution and longer-term seasonal trends in heavy metal behaviour. The data includes storm water, water seepage and lake sediment samples in the Fendrod Lake [2675 1967] and suspended sediment and channel bed samples from the adjacent Nant-y-Fendrod river system (Blake *et al.*, 2003).

More widespread and systematic geochemical datasets were collected as part of the BGS Geochemical baseline (G-BASE) project, described below. In addition, geochemical data from site investigation reports provide valuable information, particularly for developed sites.

### **Geochemical baseline (G-Base) data**

As part of an ongoing BGS urban soil geochemical survey, 373 soil samples were collected from the region in 1994, at a sampling density of 4 samples km<sup>2</sup>. The area included Swansea, Neath and Port Talbot, and the Mumbles area of the Gower Peninsula, but excluded the middle Crymlyn bog area. Sampling methodology and techniques of data analysis are fully described in Fordyce *et al.* (In press). The data was intended to provide information on the extent of contamination in an urban area; therefore providing basic information that relates to planning, remediation, sources of potential contaminants and possible environmental health issues (Fordyce *et al.* In press).

Both surface (0 – 150 mm) and subsoils (300 – 450 mm) soil samples were collected. The legacy of Swansea's industrial past is reflected in the elevated concentrations of potentially harmful elements (PHE) found in the top and subsoil. Table 2.3 presents some summary statistics for a range of elements analysed in the

topsoil (0 – 150 mm) of the survey area. For comparison, median values of the same elements found in topsoil throughout England and Wales or global means are also presented (McGrath & Loveland, 1992; Reimann & Caritat, 1998). For most of the analysed elements, the median value obtained from the Swansea dataset exceeds the comparative median value: a reflection on the extensive range of major and trace elements found in the coal and ore materials that provided the raw materials for the metalliferous industries situated within the study area. Soil samples taken at a depth of 350 – 500 mm have median values that are similar to those in the topsoil (Table 2.3). Such elevated concentrations of metals found at this depth in the soil are unusual. Typically, elemental concentrations in soils found around modern metal smelters generally show a decline in metal concentration with depth, generally within the first 200 – 300 cm. The extent is dependent on the metal, time since deposition and soil properties such as texture and pH (Sterckeman *et al.* 2000; Karczewska, 1996). One reason for enhanced metal contamination in the surface soil is the large sorption capacities of soil organic matter and clay minerals that means that most of the metals are retained within the upper part of the profile. However, the strongly acid soils present in many parts of Swansea (Table 2.4) may increase mobility and downward translocation of many of the metals. Alternatively, substantial mixing of waste materials with the soils may have occurred.

Using GIS to plot elemental concentrations demonstrates that many of the metals had similar distributions (Morley & Ferguson, 2001). Examples of proportional symbol maps for As and Cu in surface soils for the Swansea area are shown in Fig. 2.8. The highest concentrations of both elements are generally found in the three major industrial areas of the study area: the Docks, the River Neath valley and the River Tawe valley. In addition, concentrations are also enhanced along some transport routes. Similar spatial distributions of metals around industrial areas and transport

routes have been found in other urban geochemical surveys (Imperato *et al.* 2003). Fig. 2.8 also demonstrates that there appears to be widespread lesser contamination of As and Cu across the entire study area. Over 90 % of samples exceed the most conservative DEFRA Soil Guideline Value for As of  $20 \text{ mg kg}^{-1}$  (DEFRA, 2002). Likely contamination pathways include blown ore dust, particulate deposition from the smelters and from the coal that was burnt in both industries and households. For example, it is known that the redistribution of locally available materials which included metallic waste, slag and spoil was used for building projects such as embankments and this transport of material would have spread contamination.

## Hydrogeology

Local domestic water supply has been met from external surface water sources, although some thought has been given to the use of waters of suitable quality from former coalmines for public use. The understanding of the hydrogeological characteristics of the succession encountered within the study area is of primary significance in modelling the flow of groundwater and hence the movement of pollutants.

Ineson (1967) outlined the bedrock hydrogeology of the South Wales Coalfield, using mine drainage data from active coalmines including inflows into workings from fracture zones and old workings, but few aquifer properties data are available for the bedrock within the coalfield (Jones *et al.*, 2000). Hydrogeological data for the Superficial Deposits is comparatively rare.

### Aquifer properties

The bedrock geology of the study area forms low permeability hydrogeological units. Early cementation led to a marked reduction of the initially high intrinsic inter-



granular permeability coarse sands to low permeability sandstones, notably within the Pennant Sandstone Formation. The jointed bedrock sandstones, siltstones and coal seams have secondary fracture permeabilities of  $0.1\text{--}0.2\text{ m/d}^{-1}$ , while interbedded carbonaceous mudstones form aquicludes (Table 2.4). Higher zones of secondary permeability ( $0.08\text{--}2.678\text{ m/d}^{-1}$ ) occur in linear fracture zones, especially along the Tawe Fault and Neath Disturbance (Fig. 2.6). Groundwater discharges, from springs, issues and seepages along coal seam outcrops and fault-controlled valleys, are typically iron oxide rich (Strahan, 1907). Additional secondary permeability developed within zones of water table oscillation associated with sea level and river base flow shifts following the last glacial maximum. These shallow horizons of weathered, iron stained and fractured sandstones form thin zones of groundwater flow.

Mine working collapse caused land surface subsidence with fracturing of overlying sandstone beds. This resulted in local increased aquifer recharge due to surface fracture development, and increased sandstone aquifer storage capacity and transmissivity due to subsurface fracture enlargement. Although documented evidence of subsidence due to mining resulting in increasing their permeability are few, Holliday (1986) indicated that flows in such zones can exceed  $500\text{ m}^3.\text{d}^{-1}$  ( $5.7\text{ l.s}^{-1}$ ).

Superficial deposits of variable thickness, extent and permeability impact upon groundwater recharge and flow patterns in the area. Typical permeability ranges for these deposits are given in Table 2.4.

### **Water quality and vulnerability**

During the early development of the Swansea conurbation, domestic water supplies were obtained from streams, wells, springs and canals. By the early-19<sup>th</sup> Century these

sources were contaminated by sewage and mine-waters (Hughes, 2000), conditions that contributed to outbreaks of cholera in the Swansea area in 1832 and 1848/9. Improved piped water supply was provided in the mid-19<sup>th</sup> Century by the Swansea Waterworks Company from local reservoirs. Many abandoned springs and wells were reopened during the 1887 drought prompting reservoir construction at Upper Lliw and Cray that now provide all domestic supply.

Groundwaters issuing from the Pennant Sandstone Formation are often iron oxide-rich (Strahan, 1907; Jones, 1998; Hughes, 2000). The few groundwater chemistry data available from the area include pH determinations from 275 shallow boreholes. These are correlated with lithostratigraphy in Table 2.4.

In the study area shallow groundwaters flow from the valley sides through shallow glacial deposits towards the rivers. In the lower reaches of the Tawe, groundwaters infiltrate made ground deposits of ashes and slags from metalliferous ore smelting, the polluted leachates formed discharging into the river.

The study area is covered as part of the Groundwater Vulnerability map Sheet 35 (Environment Agency, 1996). It is classified in its entirety as a Minor Aquifer and comprises fractured, or potentially fractured, rocks which do not have a high primary permeability, or formations of variable permeability including unconsolidated deposits. These will not produce large quantities of water for abstraction but are important for local supplies and in supplying base flow to rivers. In the study area, this category includes the Coal Measures and Warwickshire Group and drift deposits (Alluvium, Alluvial Fan Deposits, River Terrace Deposits, Glaciofluvial sand and gravel deposits).

Three soil types of high, intermediate and low leaching potential are identified, which affect the downward leaching of water and contaminants. Their properties and distribution are outlined in Table 2.5.

## Water table

A water table elevation database was compiled using data from:

- water boreholes and wells (mainly pre-1965)
- site investigation boreholes and trial pits, mainly for motorway and road construction
- groundwater discharge zones (springs, issues, shallow wells, swamps and bogs).

The use of this database is limited to indicating directions of groundwater flow and groundwater zones (described in Table 2.6) forming the basis of a groundwater occurrence conceptual model illustrated in Figs. 2.9 and 2.10.

## Conclusions

The Swansea-Neath-Port Talbot conurbation grew in response to its global significance in metalliferous smelting. As this industry declined in the latter part of the 20<sup>th</sup> Century it left a legacy of derelict land, at least in part associated with deposits of potentially hazardous waste materials, contaminated water-courses and groundwater. Redevelopment of the area, which has accelerated over recent years, requires appraisal of potential environmental hazards. It is vital that planning decisions are based upon up-to-date, accessible and readily interpretable geological information. This study aims to provide new techniques for visualising the wealth of geological data available for the area and help facilitate planning decisions.

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## Figures

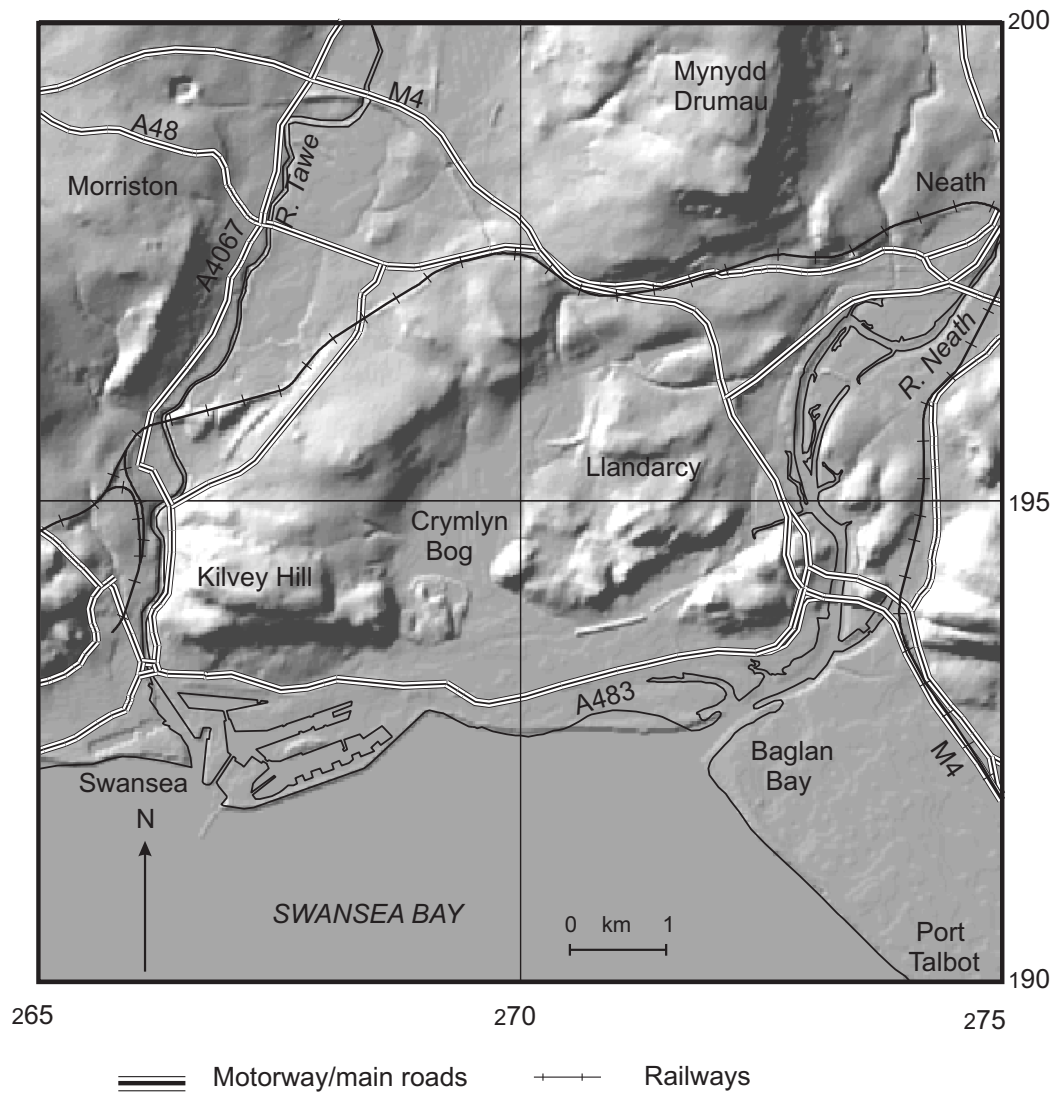


Figure 2.1 Extent of study area. NEXTMap Britain elevation data from Intermap Technologies.



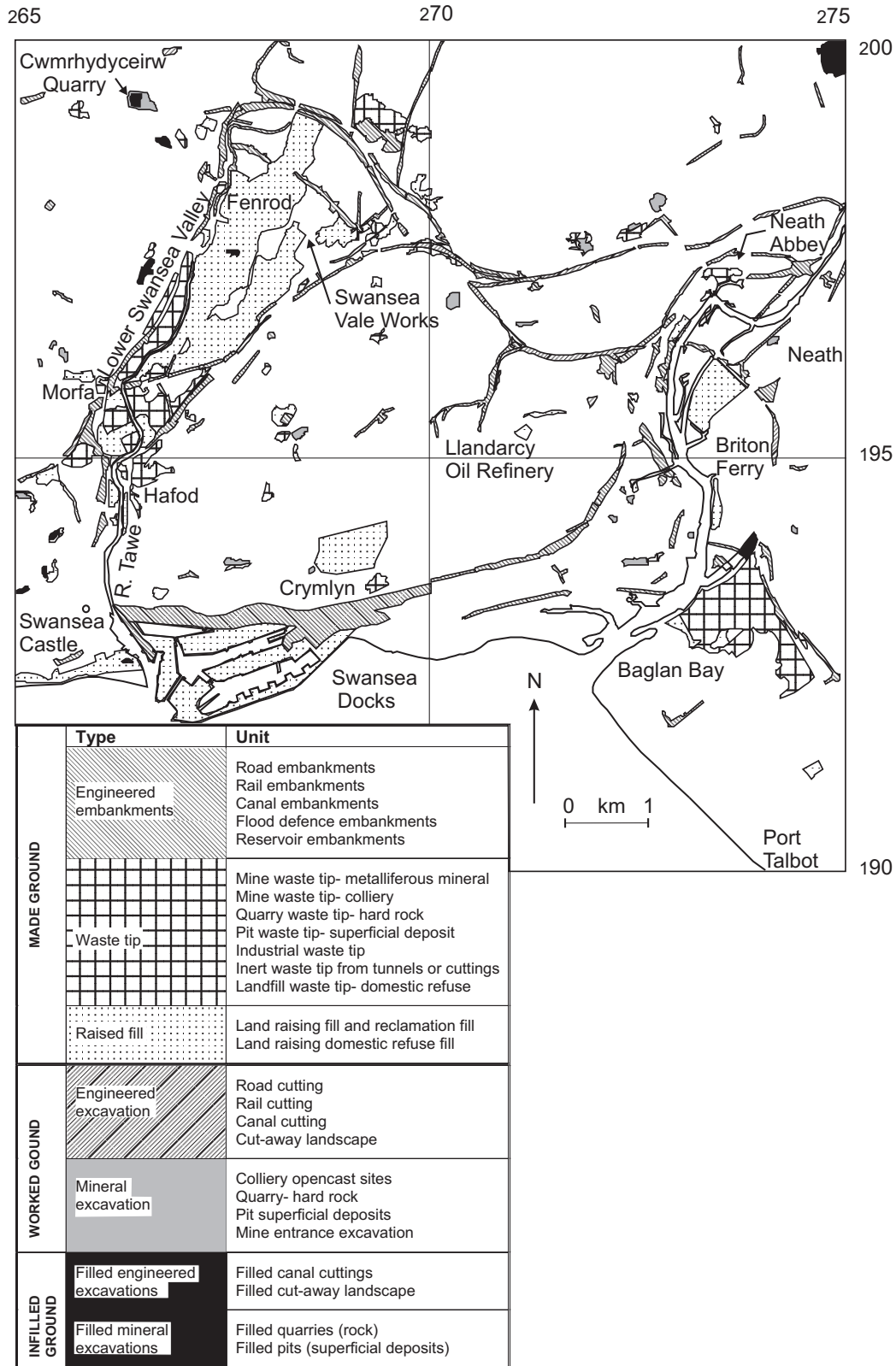


Figure 2.2 Distribution of Artificial deposits within the study area, with a Legend showing examples of the classification scheme.

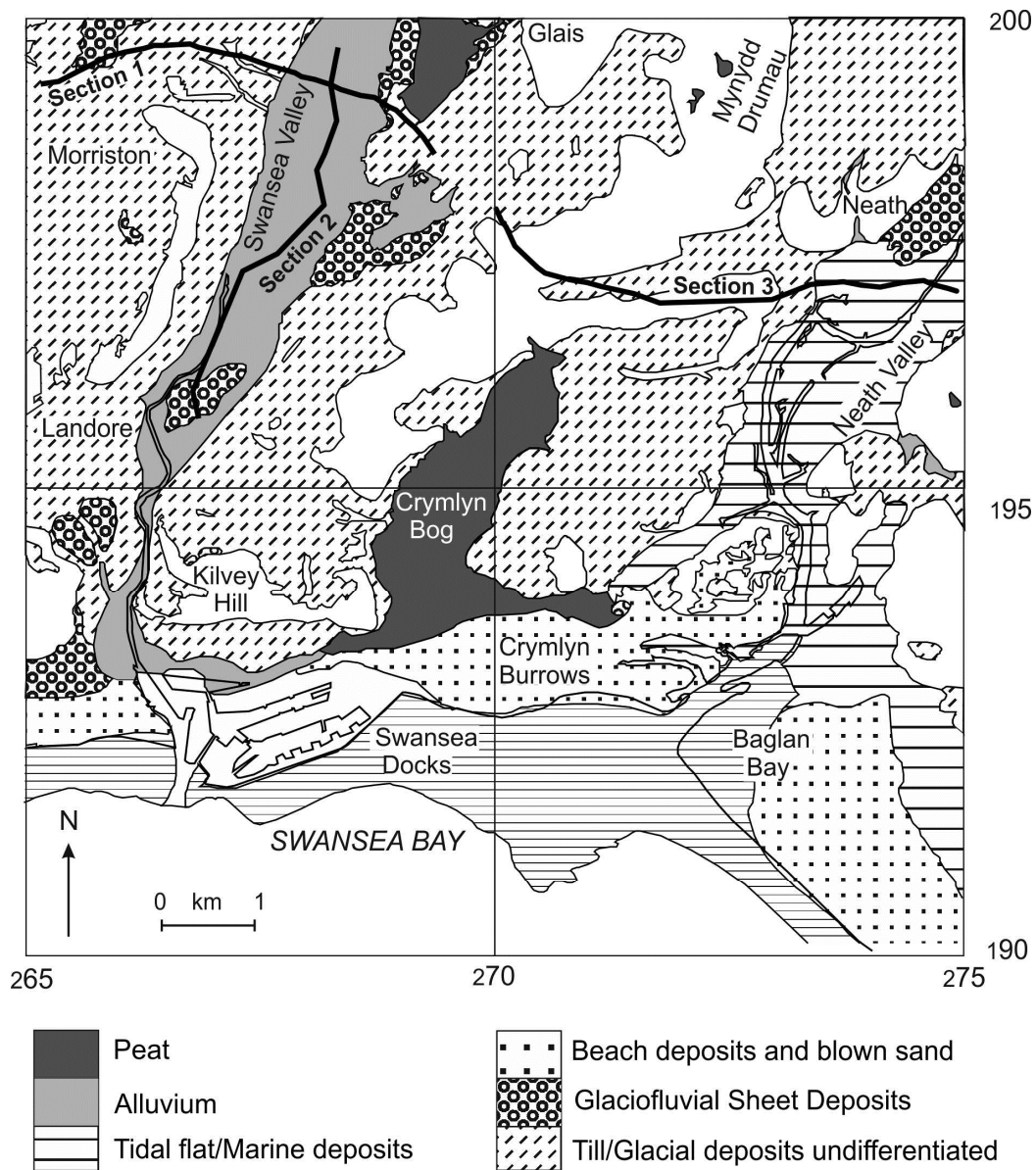


Figure 2.3 Simplified natural superficial deposit map. Note that Glaciolacustrine deposits occur only in the subsurface.

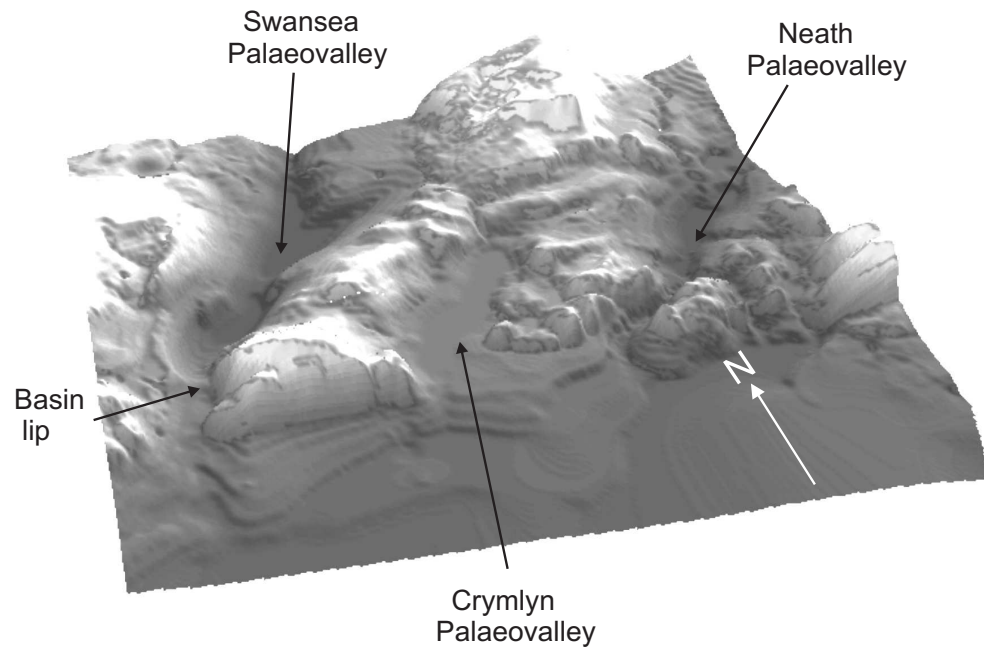


Figure 2.4 Rockhead model for the project area derived from digitised hand drawn contours, project borehole interpretations and outcrop polygons. The image is a perspective view looking toward the north.

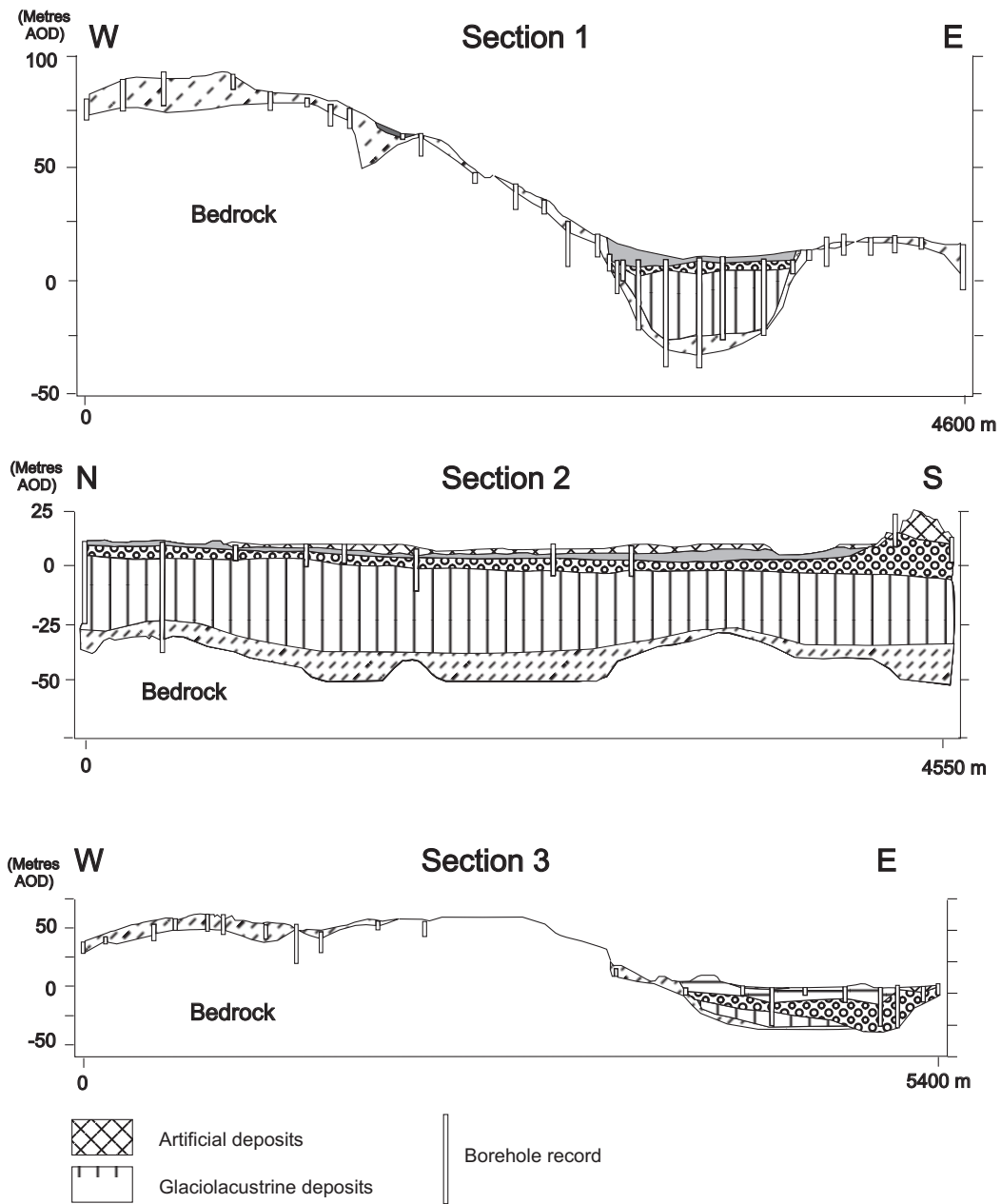


Figure 2.5 Examples of vertical 2-D sections for the Swansea and Neath valleys correlated using 3-D modelling software, GSI3D.

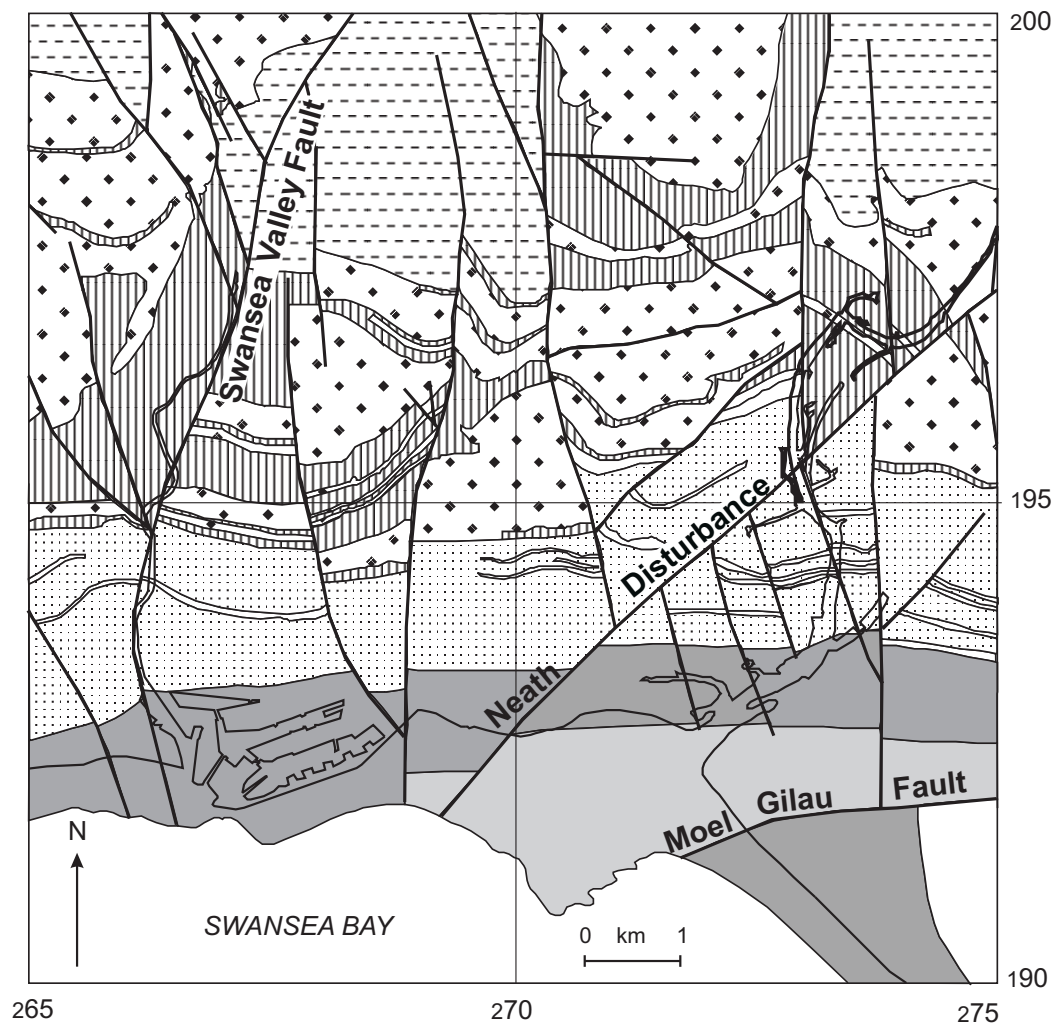


Figure 2.6 Simplified bedrock geological map showing the main lithostratigraphical units and geological faults. For legend see Fig. 2.7.

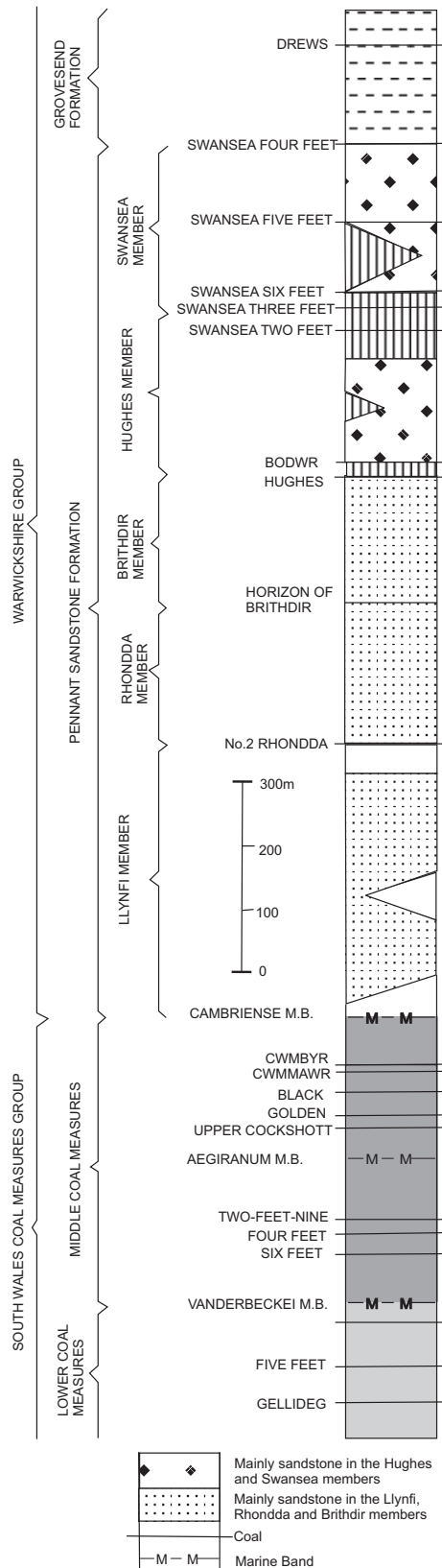


Figure 2.7 Generalised vertical section showing the stratigraphy of the bedrock geology.

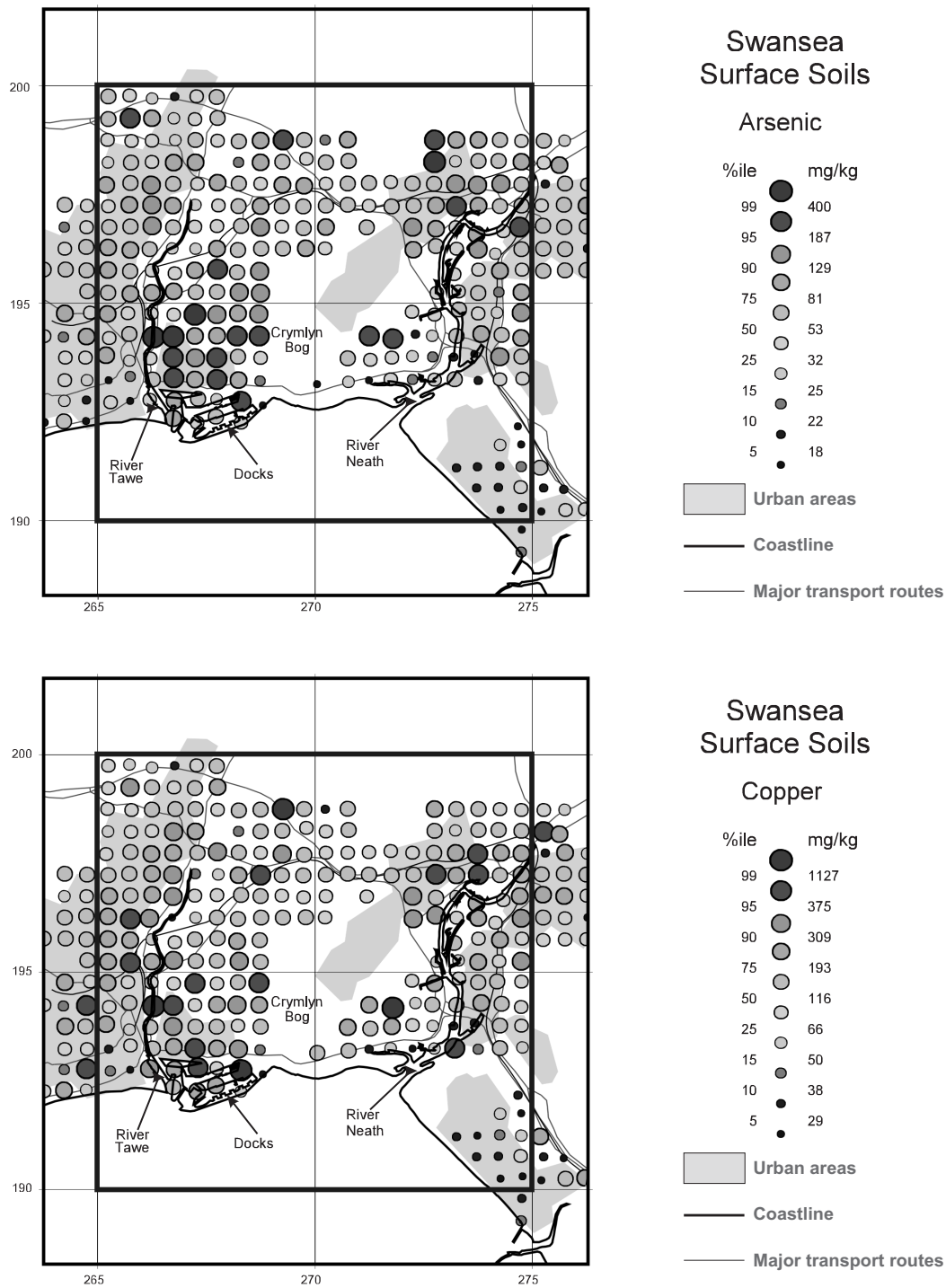


Figure 2.8 Proportional symbol maps for Arsenic and Copper showing distribution of metal concentrations throughout the Swansea area (from Morley & Ferguson, 2001).

Samples were collected under the G-SUE project undertaken by the British Geological Survey in 1994.

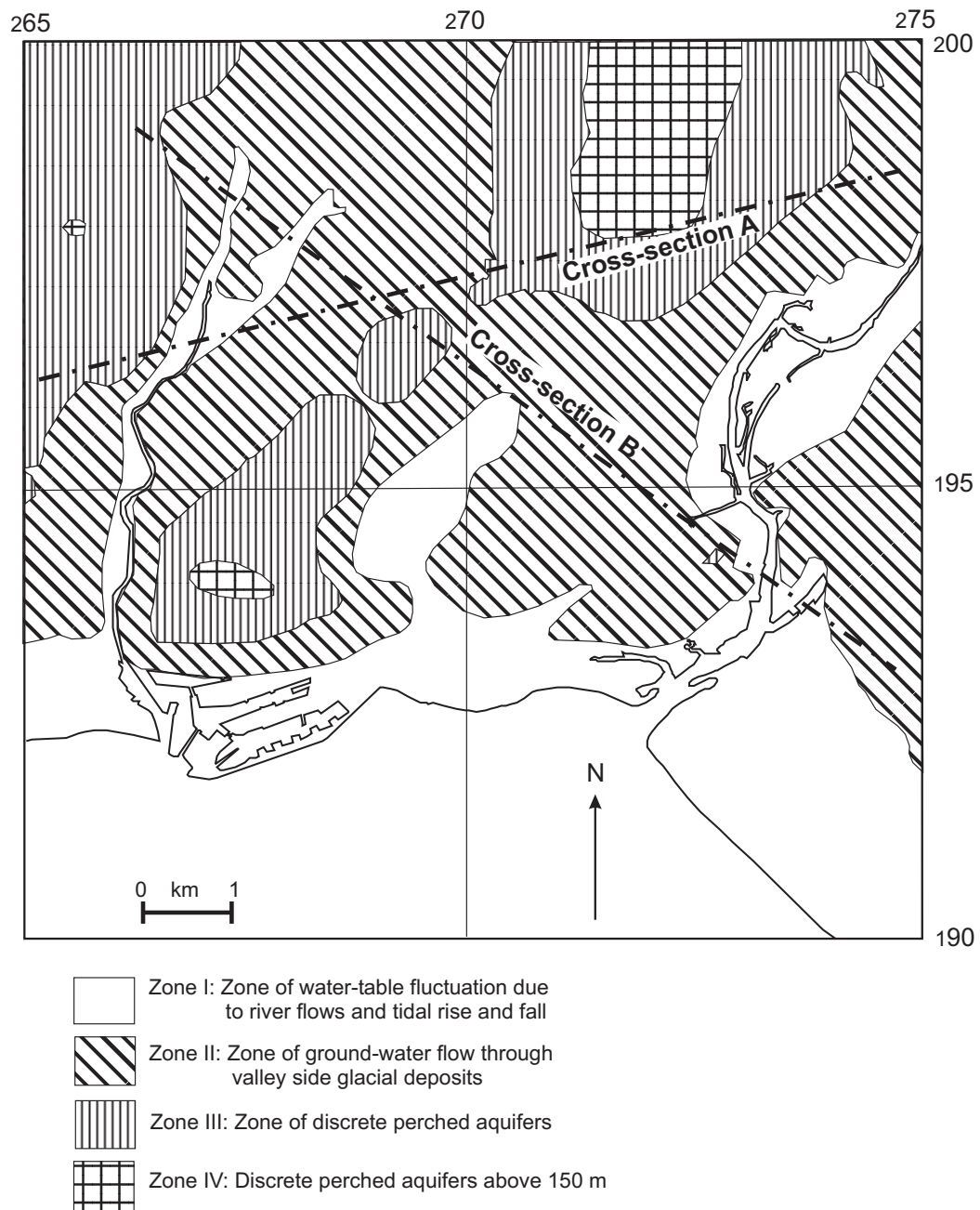


Figure 2.9 Water table primary contour interpretation.



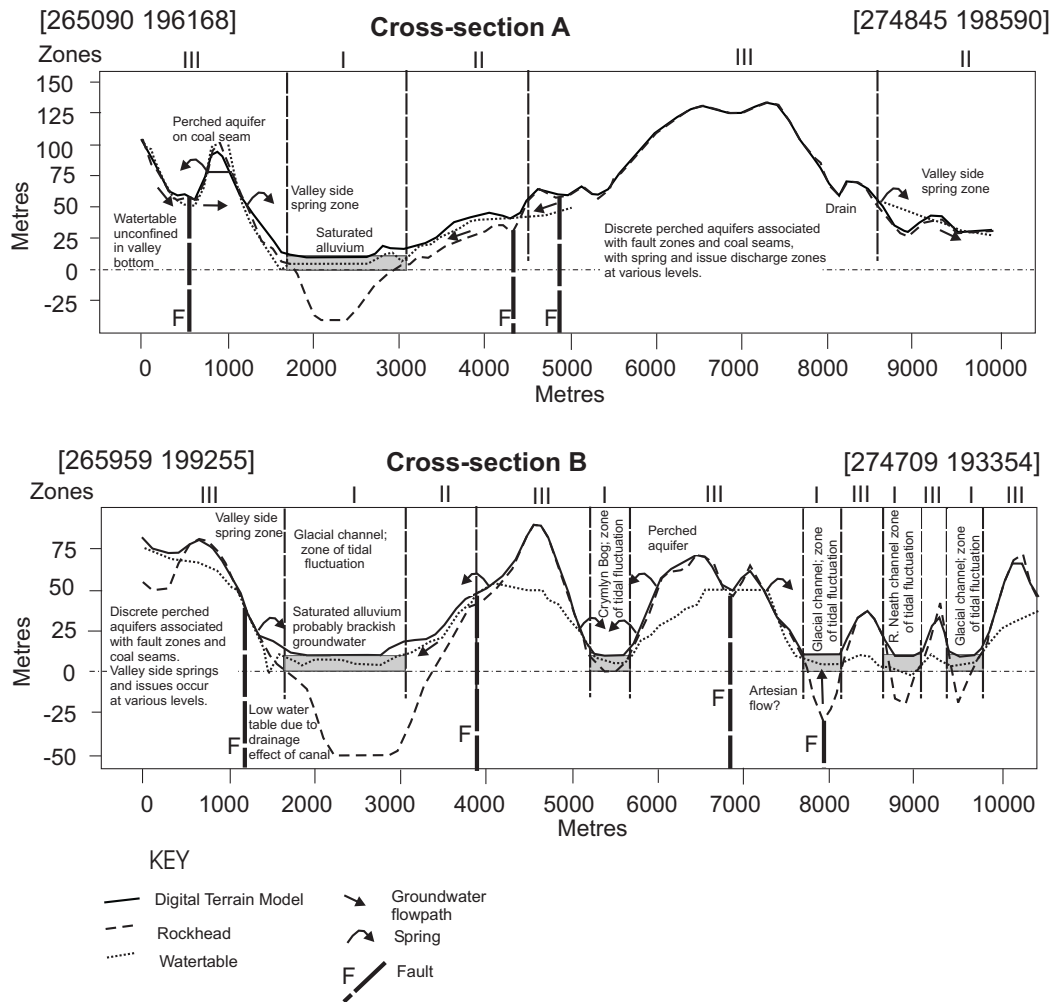


Figure 2.10 Interpretation of cross-sections shown in Figure 2.9.

## Tables

Category	Types	Distribution	Typical Contaminants*
<b>Extraction industries and mineral processing plants</b>	Coal mines and coal preparation plants	Interfluves (areas outside main river valleys)	Iron sulphide, sulphate-rich, acidic leachates with elevated levels of manganese, aluminium; combustible carbonaceous material
	Sandstone and clay pits	Interfluves	Inert
<b>Gas works, coke works and coal carbonisation works</b>	Coal carbonisation, purification, tar storage and refining, asphalt production, coke storage	Swansea docks and the Swansea and Neath valleys	Sulphate, phenols, coal tars and other aromatic hydrocarbons, oils, cyanides, sulphur and sulphides, heavy metals, e.g. chromium, copper, lead, nickel and zinc. Other hazardous substances including asbestos, benzene, toluene and xylene. Typically very acidic.
<b>Power stations</b>	Thermal power stations	Baglan Power Station	PFA with moderate risk of contamination with a wide range of metals, sulphates and sulphides, acids/alkalis, dioxins, halogenated solvents, PAHs and PCBs; PFA is typically alkaline (pH 8-9)
<b>Metal works/foundries</b>	Refining or recovery of metals, heating, melting and casting metals, pressing, rolling, extruding or stamping processes and finishing treatments, such as plating	Lower Swansea (Bridges, 1999) and Neath valleys	Cinders, slag, foundry sand and spent refractories may contain high levels of heavy metals, e.g. copper, cadmium, chromium, lead, nickel and zinc, sulphates and sulphides, acids and alkalis, asbestos, solvents, phenols and hydrocarbons. Slags associated with zinc works may have up to 11 % zinc (Bridges, 1999). Foundry sand often contains organic materials capable of generating methane
<b>Chemical works</b>	Refining and bulk storage of organic or inorganic chemicals or recovered chemicals	Arsenic works in the Swansea Valley and Swansea docks; former Baglan works	A wide range of metals, inorganic anions, acids/alkalis and organic compounds, dependent on the product of the chemical plant
<b>Oil refineries</b>	Production, refining, recovery or storage of petroleum or petrochemicals	Former Llandarcy Oil Refinery	Lead, Nickel, sulphates and sulphides, acids/alkalis and a wide range of organic compounds, including (LNAPLs), which include petroleum and diesel fuels and PAH
<b>Engineering works</b>	Manufacture of metal goods	Swansea docks and within the Lower Swansea Valley	Broad range of metals, inorganic anions, acid/alkalis and organic compounds
<b>Timber works</b>	Chemical treatment and coating of timber	West of the Swansea docks	Arsenic, Boron, Chromium, Copper, Zinc, Tin, toluene, xylene, halogenated solvents, phenols and PAHs
<b>Docks</b>	Dockland and council depots and warehouses	Swansea, Neath and Port Talbot docks	Range of contaminants dependent on products transported or stored at the sites; mainly associated with the import of metal ores and export of processed metals
<b>Petrol filling stations and bulk storage of oil/petrol products</b>	Road vehicle fuelling, servicing and repair sites and areas of bulk storage of oil and petrol products	Petrol stations widespread; bulk storage areas present to the east of Swansea docks	Chromium, Copper, Lead, Zinc, sulphates and sulphides, benzene, xylene, halogenated solvents and fuels
<b>Railway land</b>	Depots, carriage works and other engineering and storage activities	Extensively across the study area, where ashes or cinders used to raise ground	Sulphates, heavy metals, oils, solvents and paints, asbestos, PCBs and the fill may be susceptible to spontaneous combustion due to the common presence of timbers and coal debris
<b>Waste management sites</b>	Landfill on natural ground, former quarries, infilled railway cuttings and topographical depressions	Interfluvial areas	Wide range of heavy metals, sulphates, sulphides, acids, alkalis, hydrocarbons, general organics, phenols, dioxins and PCBs

Table 2.1 Main potentially contaminated land uses within the study area. Abbreviations: LNAPLs- light non-aqueous phase liquids; PAH- Poly Aromatic Hydrocarbons; PCB- Polychlorinated biphenyls; PFA- Pulverised fuel ash. \* Note that these represent typical contaminants for this land use and may not necessarily be present within sites in the study area.

Unit	Description	Distribution	Thickness	Permeability
<b>Peat</b>	Dark brown, compressible organic-rich clay and silt with abundant waterlogged plant material	Areas between the river valleys, present day Coastal zone and offshore	1-3 m	High
<b>Alluvium</b>	Soft, brown-grey, mottled, locally organic, silts, silty clays, silty sands and silty or sandy gravels, and may include bedded or imbricated silty sands and cobbly gravels	Swansea Valley and Upper Neath Valley	up to 5 m	Moderate
<b>Tidal flat/Marine deposits</b>	Soft, blue clay and silt with organic debris and thin peat lenses	Intertidal zone and lower Neath Valley	up to 15 m	Low
<b>Beach deposits and blown sand</b>	Well-sorted, unconsolidated, dark grey to brown sand, locally with shells	Coastal zone	up to 6 m	High
<b>Glaciofluvial Sheet Deposits</b>	Brown, poorly-sorted clayey sands and gravels to moderately well-sorted pebble and cobble gravels with a coarse sand matrix and scattered boulders	Swansea Valley, Neath valley, Coastal zone and offshore	up to 6 m	High
<b>Glaciolacustrine Deposits</b>	Dark grey, laminated silt and clay with lenses and layers of sand	Swansea Valley	up to 25 m	Low
<b>Till/Glacial deposits undifferentiated</b>	Stiff to hard, brown-grey silty sandy clay with gravel and boulders, and lenses of brown gravel with sand	Base of Swansea Valley and interfluvial, high ground areas.	up to 15 m	Moderate

Table 2.2 Classification of the Quaternary deposits of the Swansea – Port Talbot area.

Element	Surface soils (0 - 150 mm)			Profile soils (300 - 450 mm)			†Comparative Median (mg kg <sup>-1</sup> )
	Min	Max	Median	Min	Max	Median	
<b>As</b>	8.25	2047	53.0	1	139	47	5*
<b>Ba</b>	196	2940	397.4	167	20867	383	121
<b>Cd</b>	0.45	61	2	0.5	32	1	0.7
<b>Co</b>	5.08	238	23.46	7	141	24	9.8
<b>Cr</b>	20.49	565	74.4	24	757	83	39
<b>Cu</b>	6.6	1446	113.7	10	3321	113	18.1
<b>Mo</b>	0.15	31.8	2.2	0.15	48.5	2.7	1.2
<b>Ni</b>	8.41	349.2	35.75	8	966	35	22.6
<b>Pb</b>	19.64	14714	224.4	13	23782	157	40
<b>Sb</b>	0.5	111	4.0	0.5	105	2	0.5*
<b>Sn</b>	2.99	918.5	30.9	2	2009	21	4*
<b>U</b>	0.25	5.50	1.60	0.25	9.2	2.1	2.7*
<b>V</b>	27.48	297.50	85.00	44	351	91	90*
<b>Zn</b>	41.07	19047	314.7	33	30305	263	82

Table 2.3: Summary statistics (n = 373) for total soil element concentrations in surface soils (0 – 150 mm) and profile soils (300 – 450 mm) from the G-BASE survey of Swansea. All values in mg kg<sup>-1</sup> unless stated.

†England and Wales data taken from McGrath & Loveland (1982)

\*World data taken from Reimann & Caritat (1998).

Lithostratigraphical unit	Permeability (m.d <sup>-1</sup> )	Min pH	Max pH
<b>Made Ground</b>	0.028 – 2.16	4.4	11.7
<b>Alluvium</b>	0.251 – 8.64	6.4	9.7
<b>Blown Sand</b>	No data	7.3	9.4
<b>Beach &amp; Tidal Flat Deposits</b>	0.033 – 6.57	7.0	9.7
<b>Glaciofluvial Deposits</b>	0.173 – 95.04	7.5	8.2
<b>Glaciolacustrine Deposits</b>		6.5	8.7
<b>Till</b>	0.181 – 2.592	4.3	8.8
<b>Grovesend Formation</b>	0.1 – 0.2	6.6	8.1
<b>Pennant Sandstone Formation</b>		6.7	8.0
<b>South Wales Coal Measures</b>		7.1	7.8

Table 2.4 Permeabilities and groundwater pH correlated with lithostratigraphic formations within the study area.

Soil Type	Unit	Properties	Areas affected
<b>Soils with high leaching potential</b>	H1	Shallow soils which transmit liquids or are by-passed by liquids flowing to rock, gravel or groundwater.	Crymlyn Bog peat; Neath Valley tidal deposits; Tawe Valley glacio-fluvial and terrace deposits
	H2	Deep permeable soils which transmit pollutants by rapid drainage with low attenuation.	Crymlyn Burrows beach and dune sands
	H3	Coarse textured or shallow soils which transmit non-absorbed pollutants but attenuate absorbed pollutants due to clay or organic contents.	Thin soils on bedrock outcrop areas
	U	Soil information for urban areas is less reliable, land with high leaching potential is assumed.	Much of the study area
<b>Soils of Intermediate Leaching Potential</b>	I1	Soils which transmit a range of pollutants.	Undeveloped alluvium areas along the River Tawe
<b>Soils of Low Leaching Potential</b>	L	Soils in which pollutants are unlikely to penetrate the soil layer, because water movement is horizontal, or soils can attenuate diffuse pollution.	High clay content associated with till deposits

Table 2.5: Groundwater vulnerability classification of soil types present within the study area.

<b>Zone</b>	<b>Altitude (above od)</b>	<b>Characteristics</b>
<b>I</b>	0-5 m	Estuaries and lower reaches of the main valleys between mean high water contour and 5 m including: floodplains and mud banks flooded by spring and autumn high tides where groundwaters in the alluvium and made ground deposits are affected by tidal shift. Areas of elevated coastal dunes (5-10 m aod), e.g. Baglan Bay are included within this category as the groundwaters within this unit are subject to tidal movement.
<b>II</b>	5-50 m	Alluvial and glacial deposits in valley bottoms and sides. Groundwater in discontinuous superficial alluvial, glacial and made ground deposits, may be in hydraulic continuity with bedrock aquifers. Groundwater levels affected by flows from drains, leats and canals and pumping from now closed shallow mines. Water levels not affected by tides but by rainfall and drought. Complex patterns of groundwater interflow between units affects groundwater chemistry, especially in deposits below former metal works built on the higher flood plains (5-10 m) of the Lower Swansea and Neath Valleys. The latter sub-zone includes areas that would be at risk of flood should sea levels rise.
<b>III</b>	50-150 m	Groundwater located within bedrock sandstones, shales and coal seams. Springs and seeps occur along sandstone outcrops, coal seams and fracture zones. Collapse of underground workings fracture overlying sandstones, altering patterns of water recharge and flow.
<b>IV</b>	>150 m	Groundwater occurs as perched aquifers in jointed sandstone beds separated by impervious shales of the Pennant Sandstone Formation. Springs issue from sandstones.

Table 2.6: Conceptual groundwater zones within the study area.